Exploring Control Strategies in ATC: Implications for Complexity Metrics

Jonathan Histon &
Prof. R. John Hansman

JUP Meeting,
June 21-22, 2001.

Introduction

- **Project Goal**
  - ❏ Develop operationally useful measures of complexity.
- **Why study complexity?**
  - ❏ Cognitive challenge of ATC is one of the fundamental limits that restricts the capacity of a piece of airspace.
  - ❏ Previous research has concentrated on measures of that cognitive challenge in the Free Flight environment.
    - ◆ E.g. “Dynamic Density”
  - ❏ <u>However, these measures do not take into account the inherent structure present in the current operational environment.</u>
- **Incorporating structure would:**
  - ❏ Increase the sophistication of predictions of potential controller overload situations (E.g. Monitor Alert in ETMS).
  - ❏ Provide guidance to airspace redesign projects.

Our Approach

- **Collaborative effort, sponsored by FAA, with partners at Centre d'Etudes de la Navigation Aérienne (CENA) in France.**
- **Step 1 - Literature Review**
  - ❑ Current metrics
    - ◆ Simple count of Number of Aircraft in a Sector
  - ❑ Previously proposed metrics
    - ◆ NASA's Dynamic density, Wyndemere Corporation
- **Step 2 - Field Observations**
  - ❑ Case study at Boston TRACON
    - ◆ Comparison of sectors – what makes one harder than another?
  - ❑ Visits, interviews at Boston Center, Montreal Center
  - ❑ Generated preliminary list of key factors in complexity.
  - ❑ "Flight Explorer" and Analysis of Current System Operation
- **Step 3 - Proposing metrics**
- **Step 4 - Validating those metrics**

System Response to Complexity

- **Why study structure in the current system?**
  - The ATC system is an adaptive system.
    - Biological analogy.
  - Evolve in response to controller capability limits being exceeded
    - E.g. splitting sectors, changing procedures
  - Therefore, observing the current system can provide insight into complexity limits
    - Use of Structure
    - Maximum observed complexity in sectors.

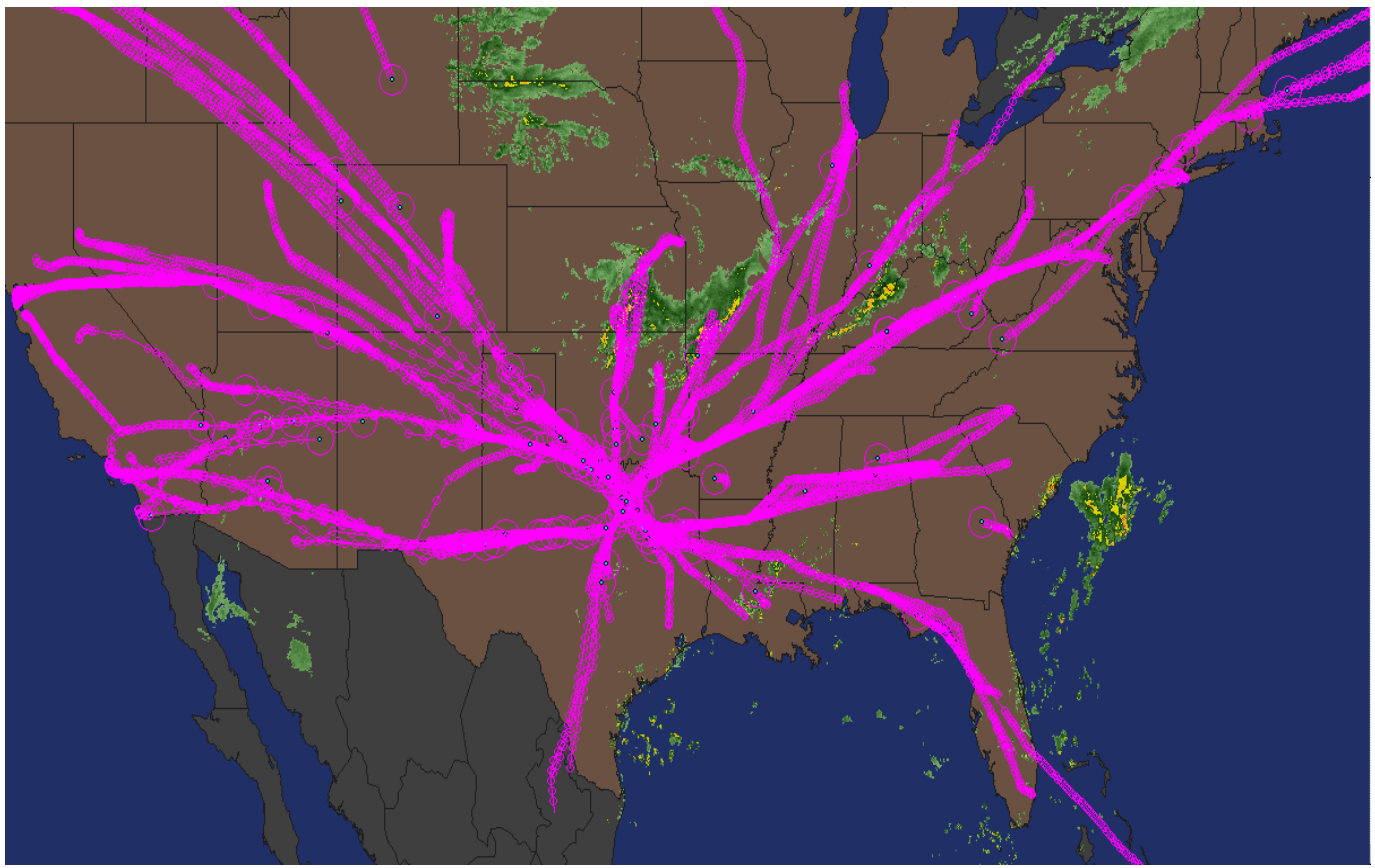
“Flight Explorer”

- **Capabilities:**
  - ETMS feed in real-time on desktop PC
  - IFR flights in United States, Canada, and United Kingdom.
  - For each flight:
    - Present position, Altitude, Speed vector
    - Historical radar track
    - Current flight plan
  - Displays:
    - Weather images
    - Sector boundaries
    - Airways, Navaids etc…
- **Technical details:**
  - Commercial service provided by Flight Dimensions International (www.flightexplorer.com)
  - Update rate ~ 1 minute

Preliminary Observations

Dallas Fort-Worth

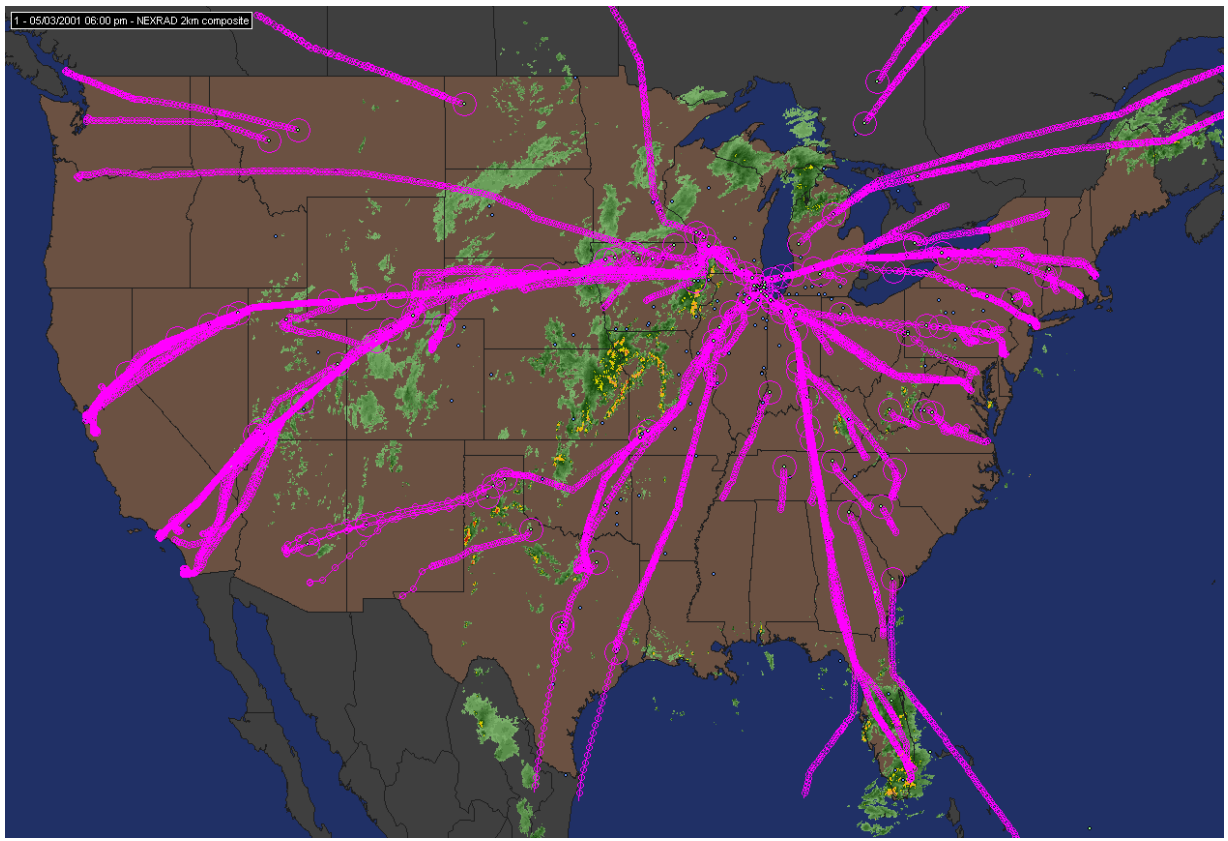
- Aircraft are condensed into distinct flows feeding 4 arrival fixes.



- June 20, 2001 12:19 p.m. 153 Aircraft In-bound

Chicago

- **Presence of branching structure consolidates aircraft into flows, reducing the complexity of the ultimate merging process**



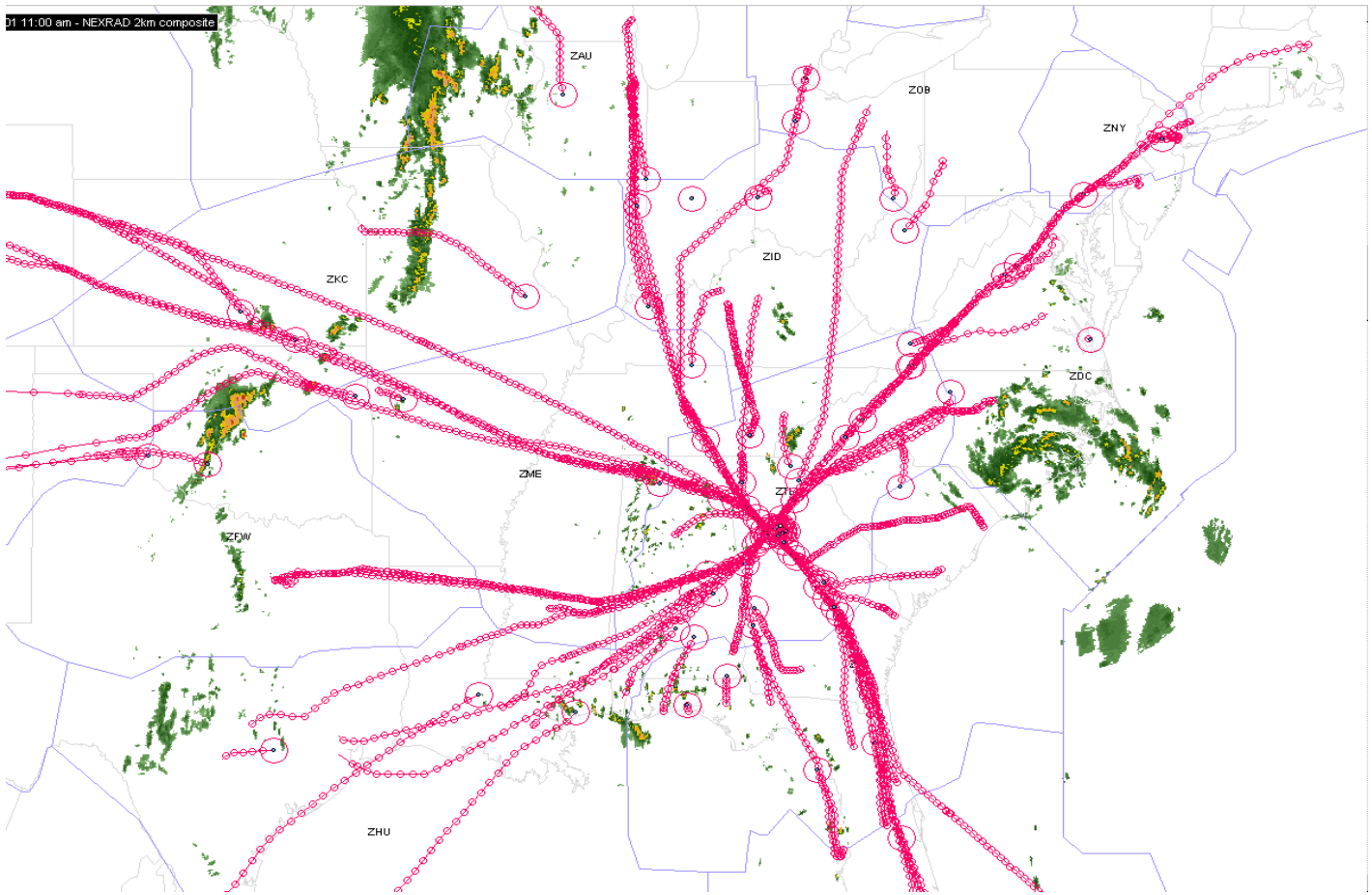
- **May 3, 2001 6:20 p.m. 295 Aircraft In-bound**

Atlanta

- Condensation and merges have reduced 116 trajectories at airport to 4

ARTCC Boundaries

Route Flown



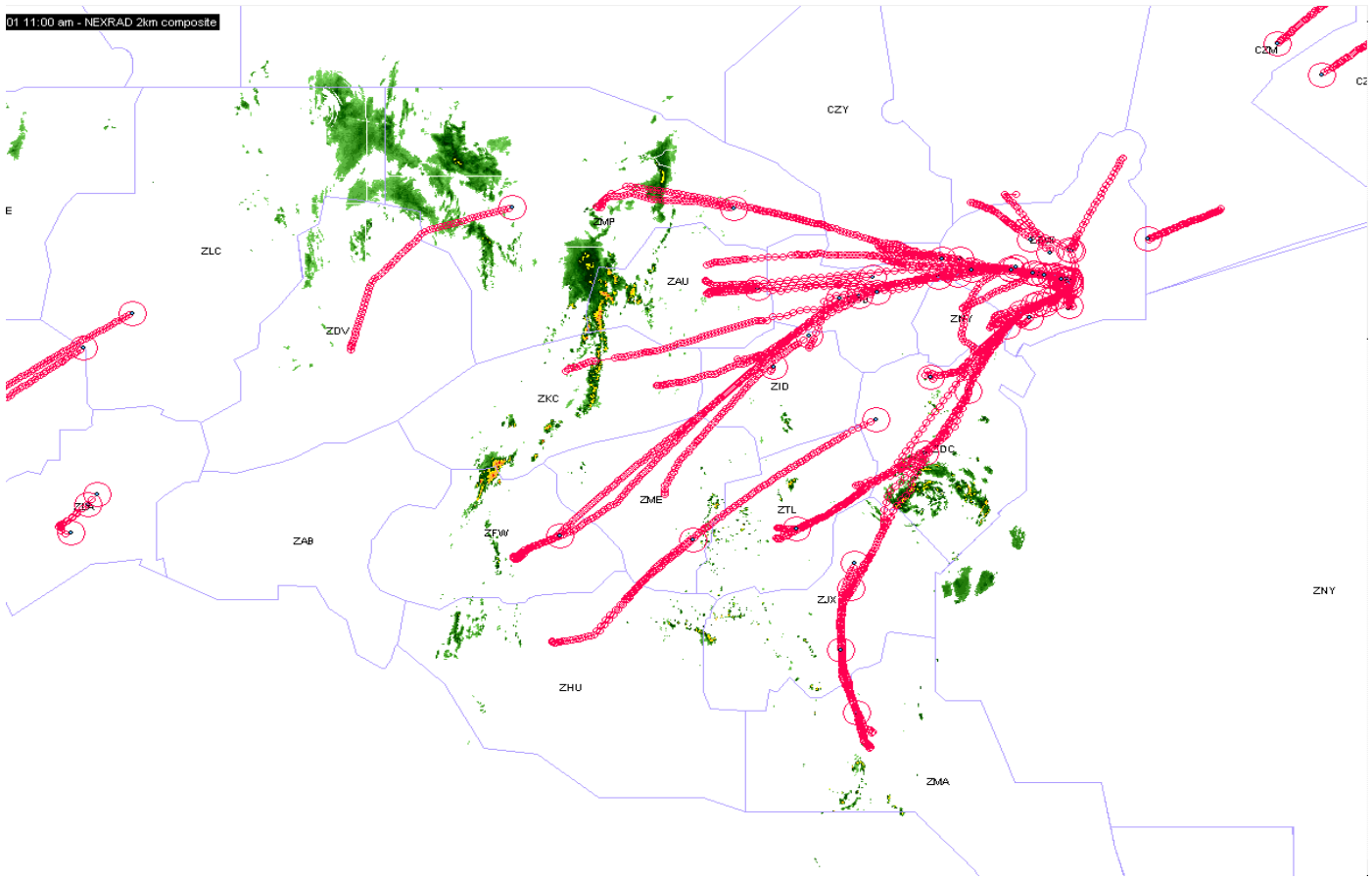
- June 14, 2001 11:15 a.m. 116 Aircraft In-bound

Boston

- Similar branching pattern is observed

ARTCC Boundaries

Route Flown



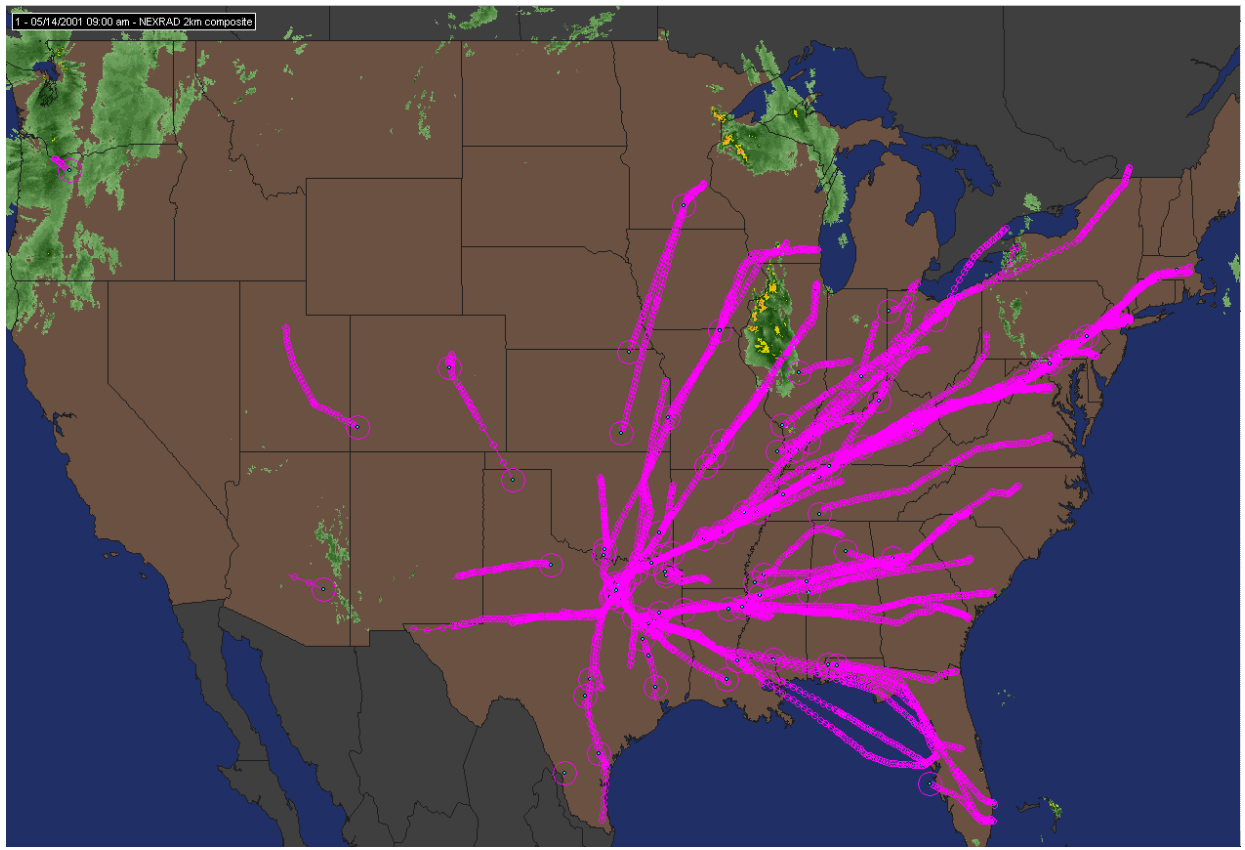
- June 14, 2001 11:21 a.m. 78 Aircraft In-bound

Dallas

- **Complexity is increased by need to handle large groups of aircraft in a short time.**

ARTCC Boundaries

Route Flown



- **May 14, 2001 9:18 a.m. 117 Aircraft In-bound**

San Francisco

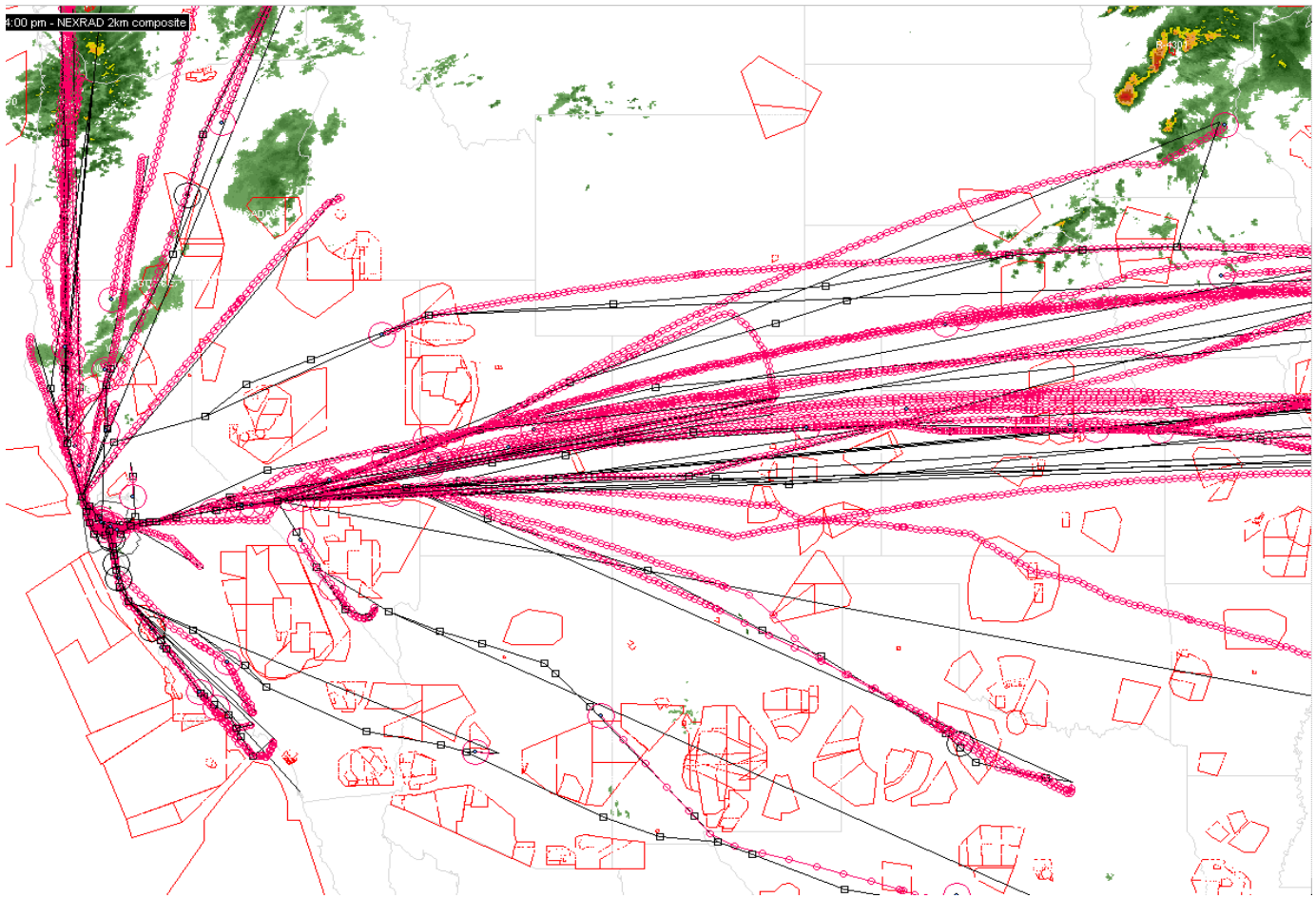
- Special use airspace provides additional constraints

Special Use Airspace

ARTCC Boundaries

Route Flown

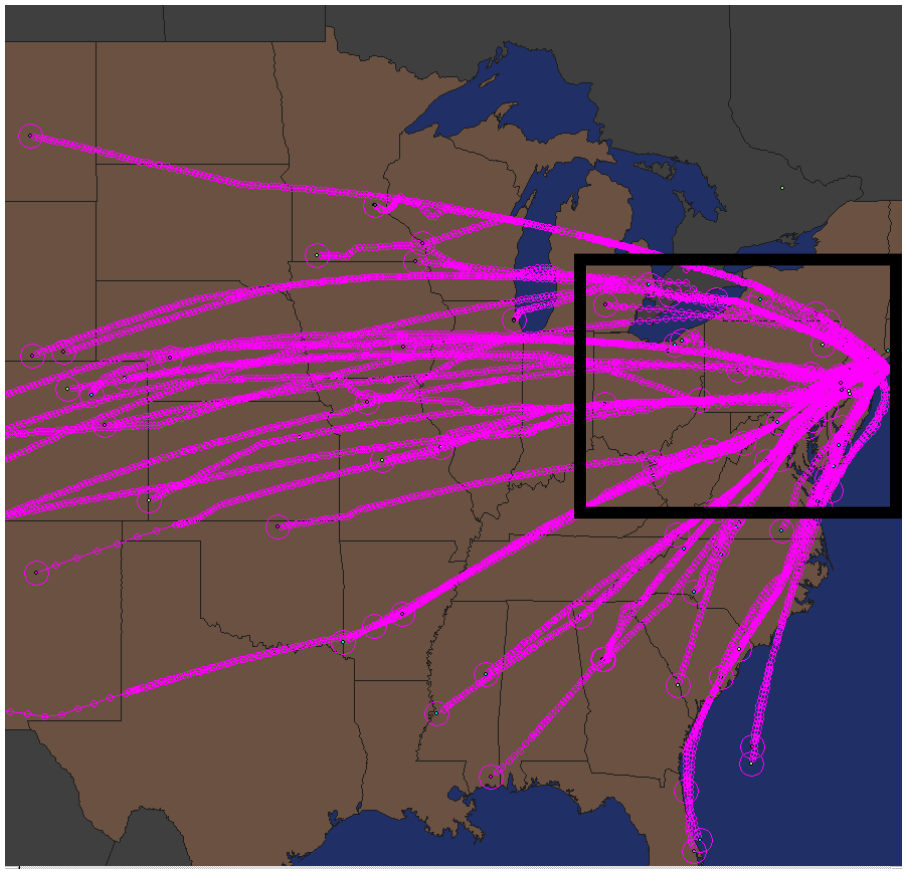
Flight Plan

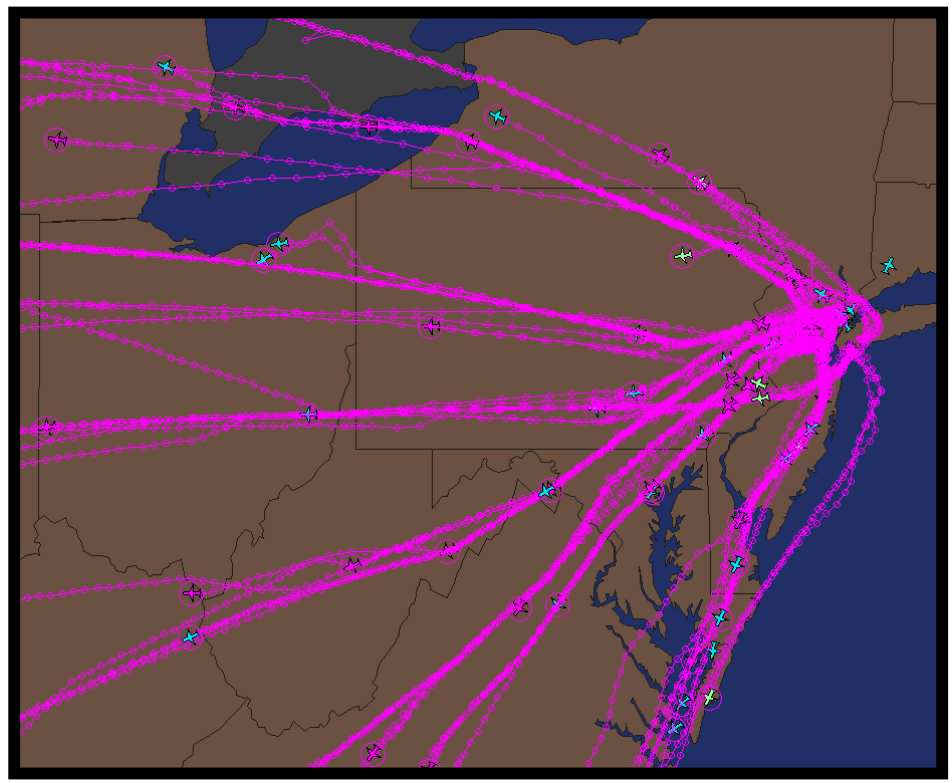


- June 11, 2001 4:13 p.m. 78 Aircraft In-bound

New York City (LGA, EWR, JFK)

- Departures can be structured as well:





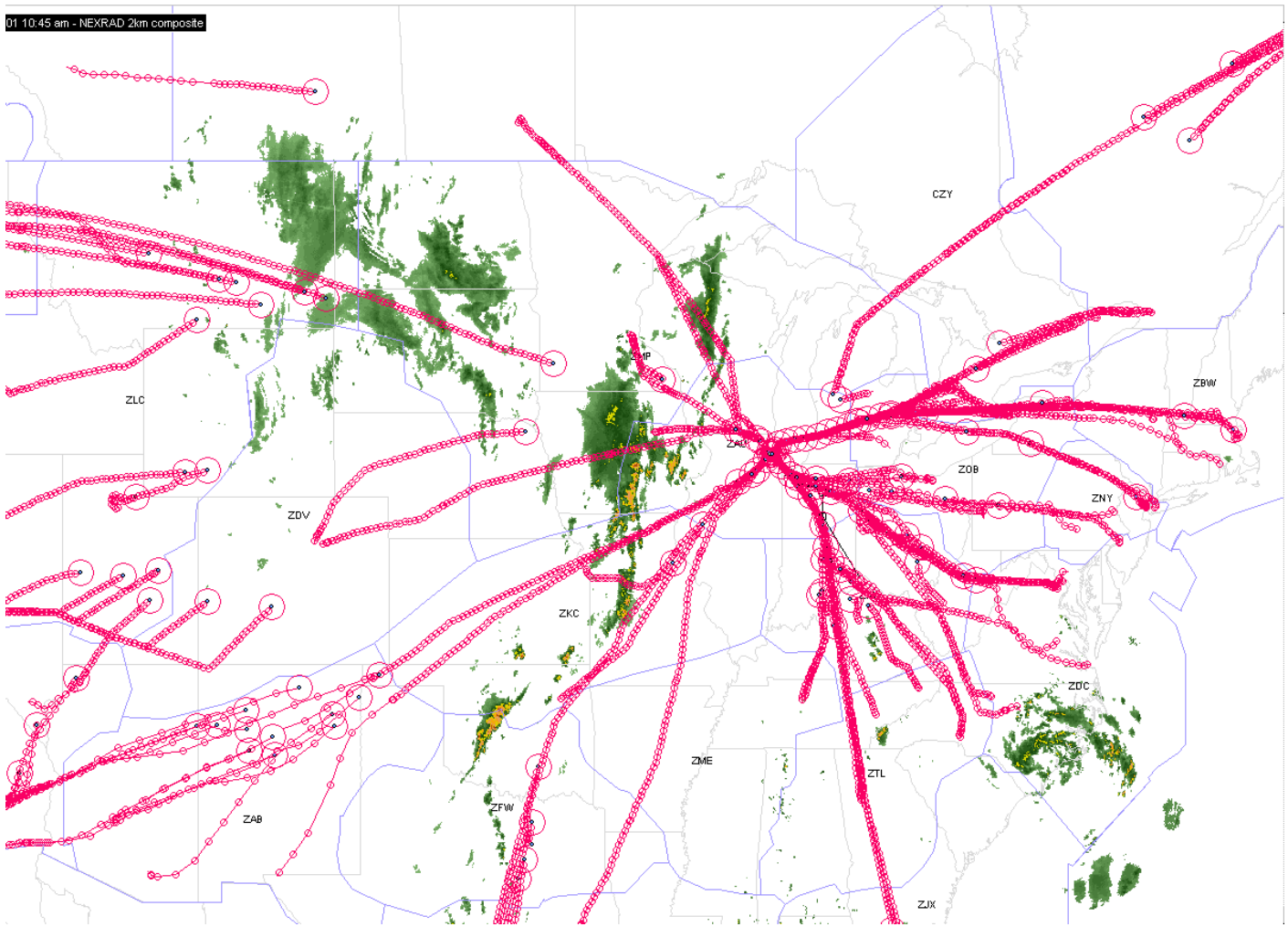
- April 30, 2001 2:40 p.m. 135 Aircraft Out-bound

Chicago

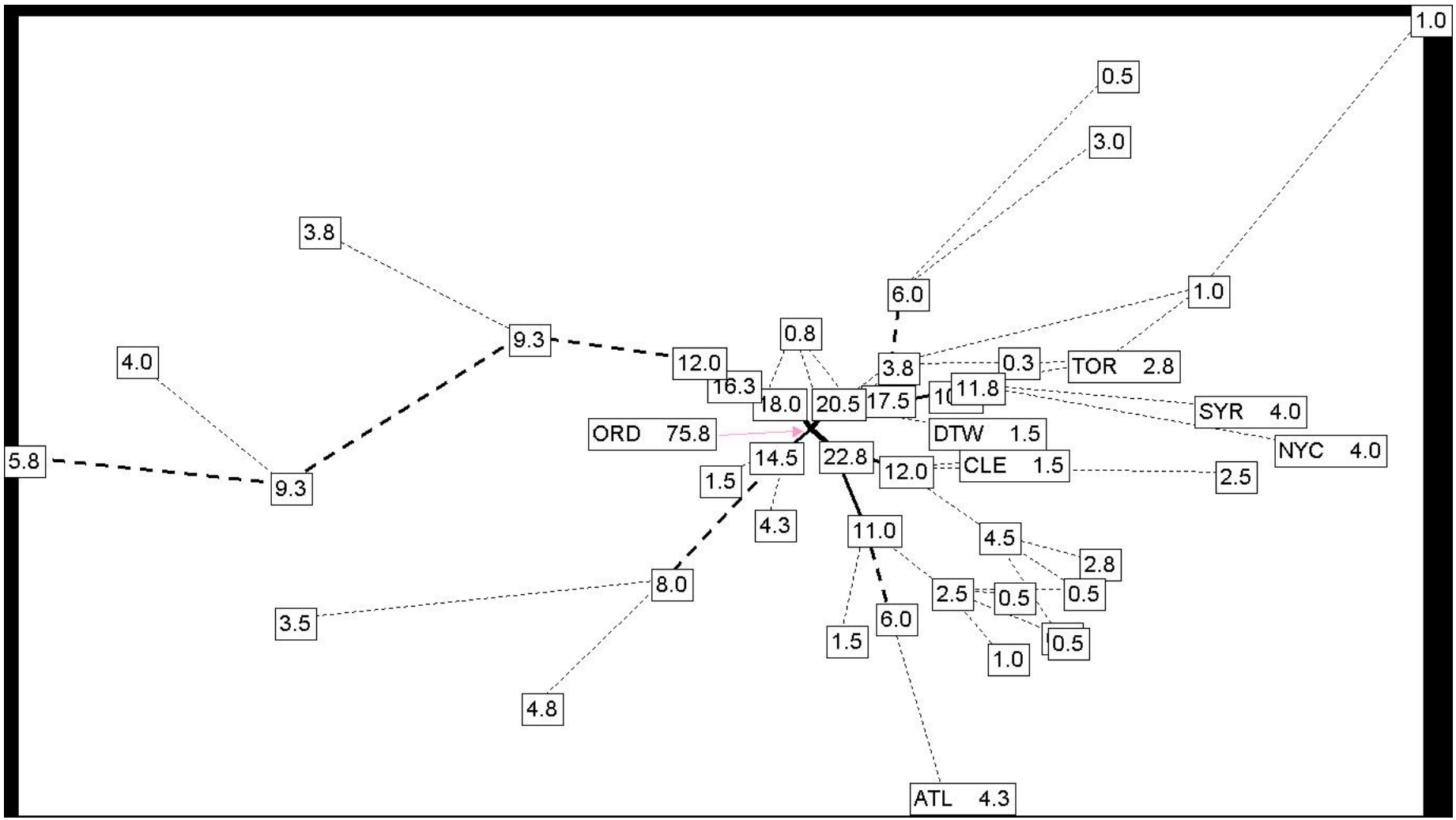
- June 14, 2001 11:04 a.m. 160 Aircraft In-bound

ARTCC Boundaries

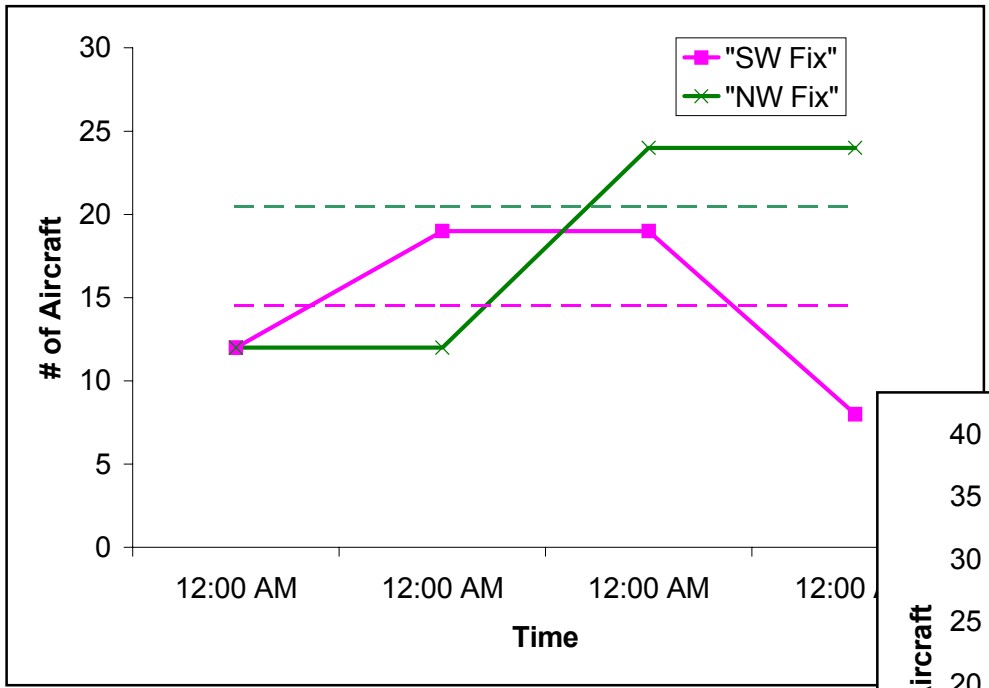
Route Flown



Branching Structure, Chicago
Aircraft / Hour, Averaged 11:00 – 15:00

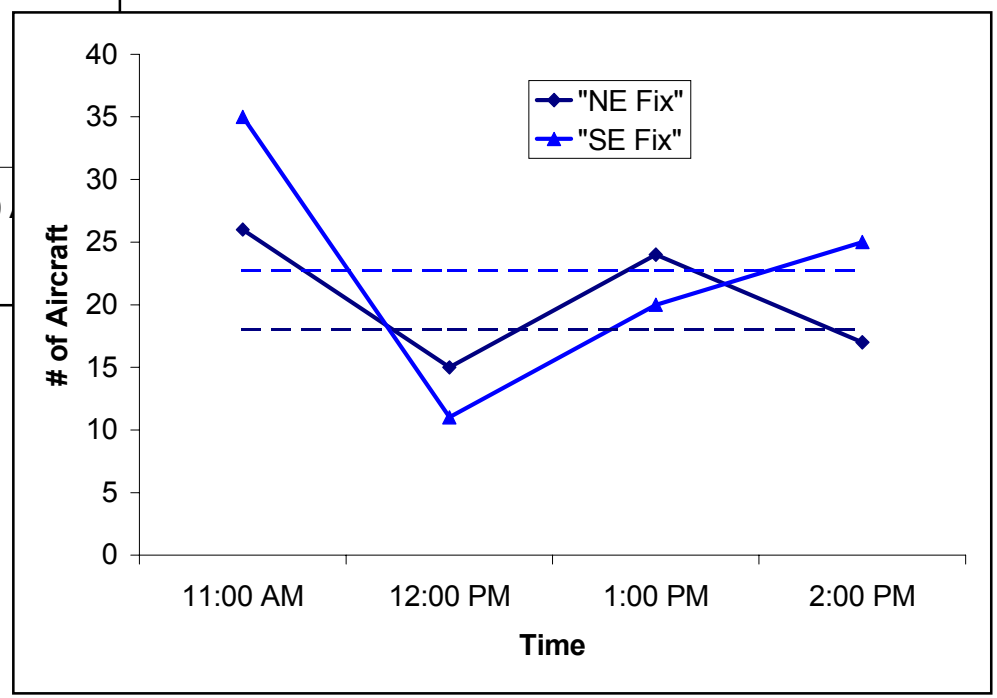


Temporal Variations in Demand



West Fixes

East Fixes

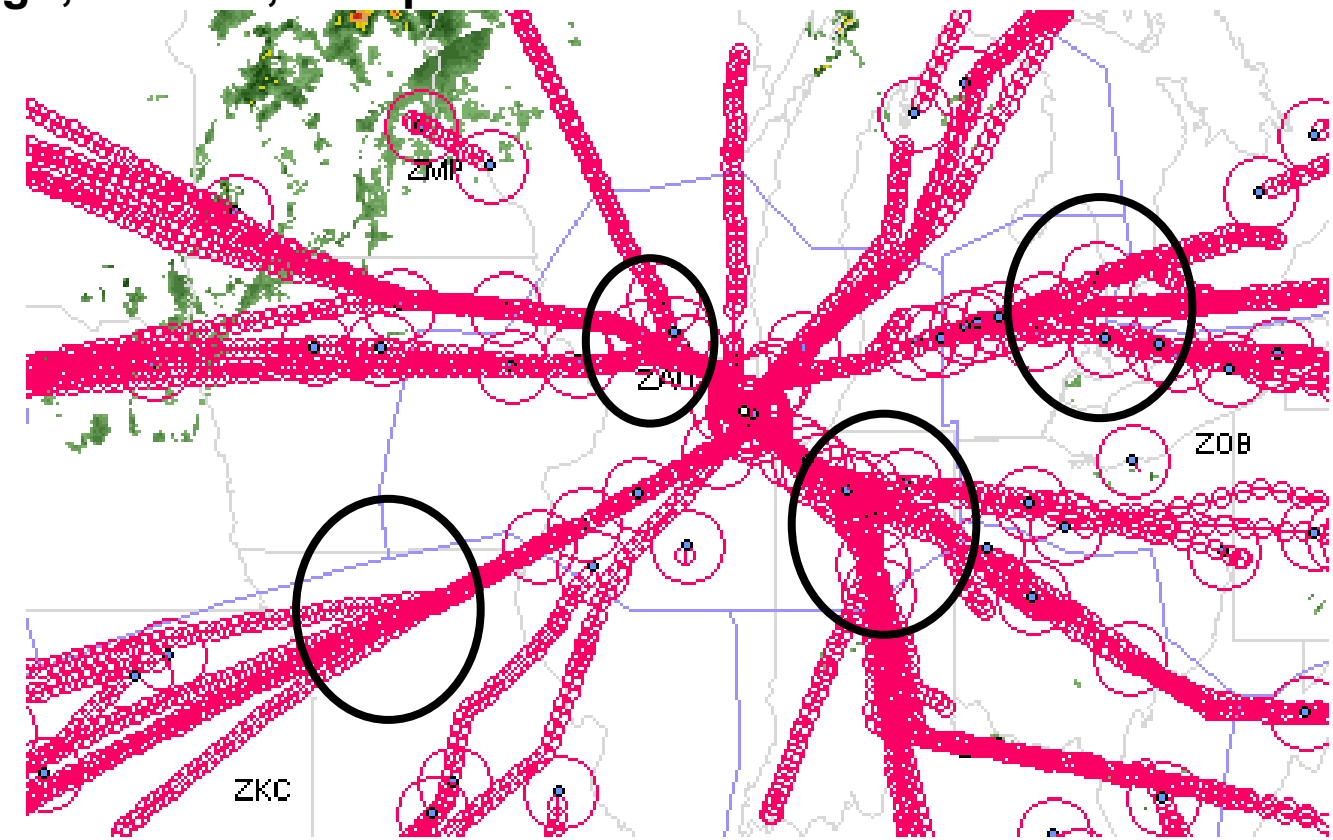


Flows at a Merge Point

- Observed maximum of 3 significant flows at any merge point.
- Implies number of flows to be merged is a limiting factor in complexity.
- Example: Chicago, June 11, 2:12 p.m.

ARTCC Boundaries

~~Route~~ Flown



Flows at a Merge Point

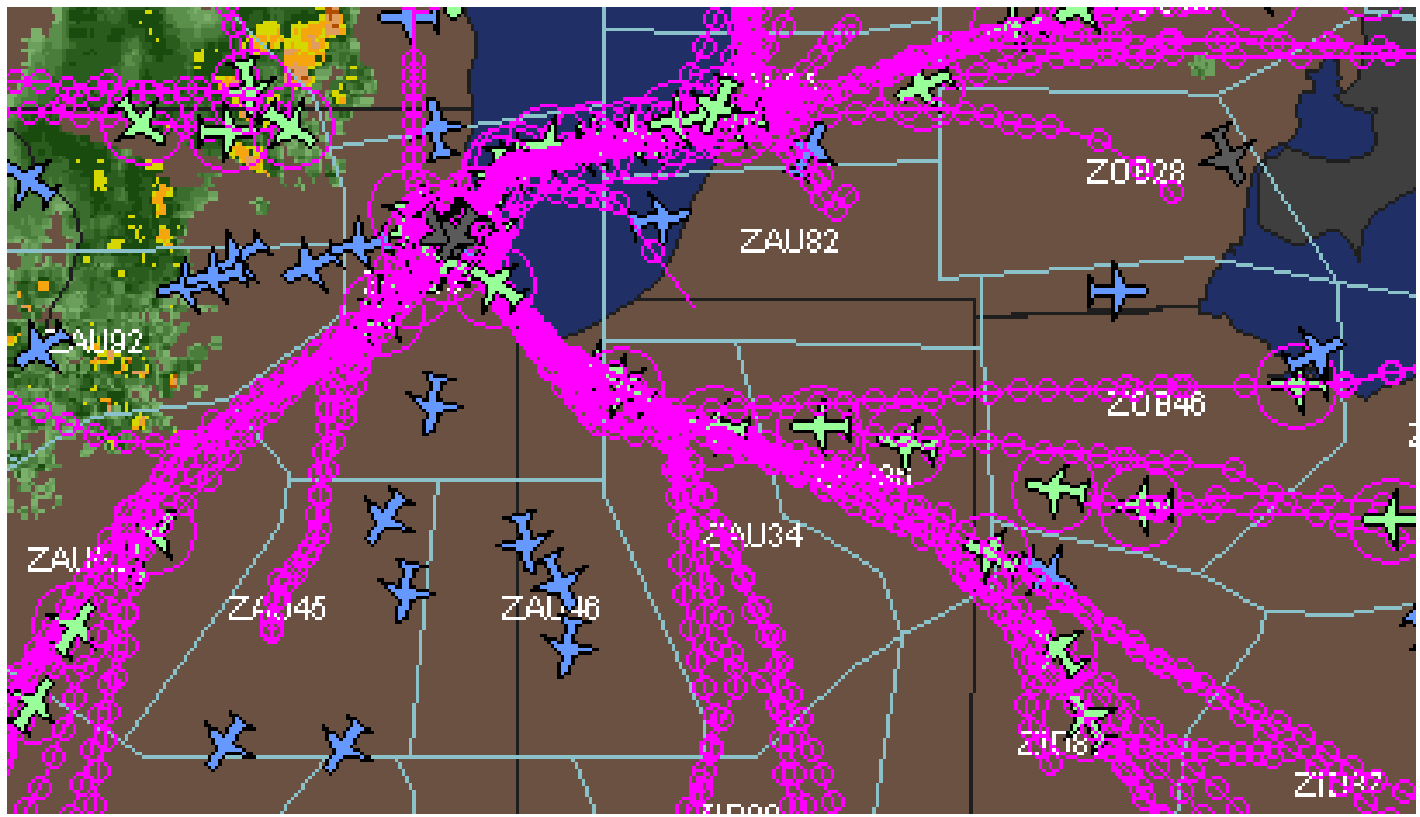
- Generally observe 1 merge point only in a sector
- Suggests performing merges is a limiting factor in complexity.
- Example: Chicago, May 3, 8:59 p.m.

Sector Boundaries

In-bound ORD

In-bound's Route Flown

Out-bound ORD



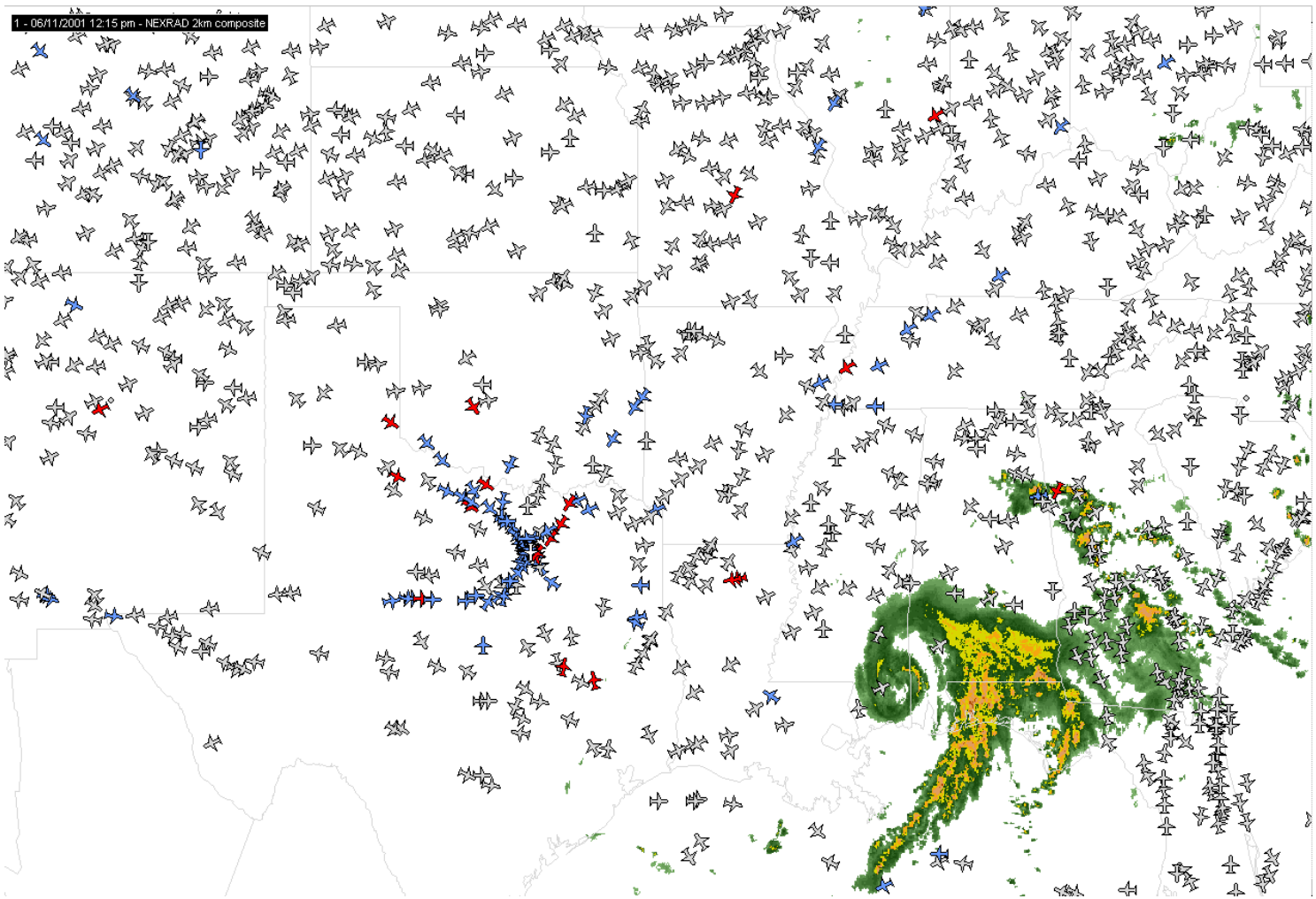
Arrival flows as part of larger system: Dallas

- June 11, 2001 12:29 p.m. 163 Aircraft In-bound (DFW/DAL)

DFW

DAL

OTHER
(> FL240)



Summarizing so far….

- **Shown there exists similar branching structure in arrival flows.**
  - ❏ Condensation points bring aircraft together to form flows
  - ❏ Flows are merged to provide final feed to an airports arrival fixes
  - ❏ Process reduces complexity of sequencing aircraft, and spreads that task across more controllers.
- **Examples of Elements Driving Complexity**
  - ❏ Special Use Airspace (San Francisco)
  - ❏ Temporal variations in demand (arrival banks in Denver)
- **Limiting Factors for Complexity:**
  - ❏ Maximum of 3 flows at a merge point
  - ❏ Only 1 merge points in a sector.

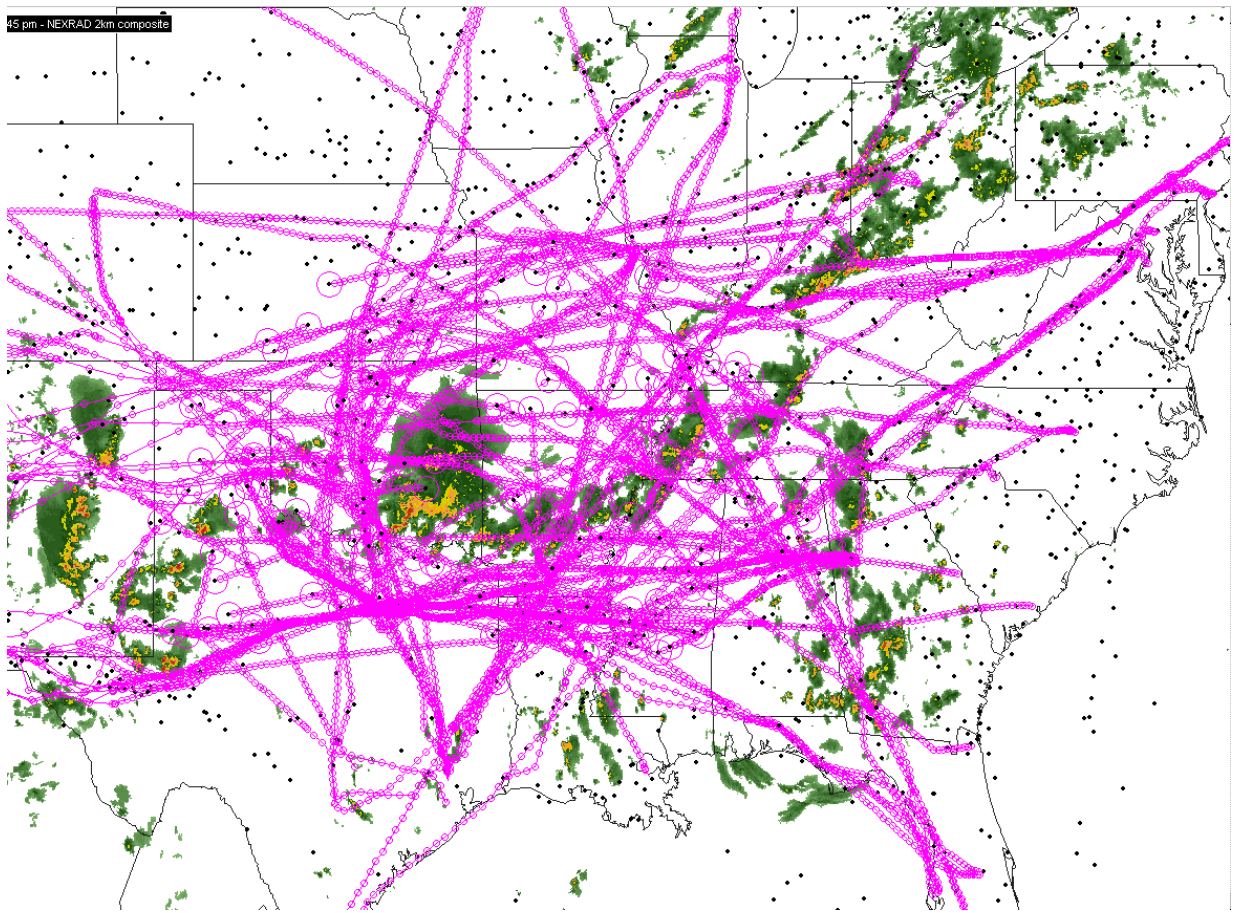
Weather, Flows, and Complexity

- **How does weather impact these flows?**
  - ❑ Rerouting
    - ◆ Chicago, May 3
  - ❑ Holding
    - ◆ Boston, April 24
    - ◆ Dallas, May 4
- **Issues for Complexity:**
  - ❑ Buffering
    - ◆ Ability to absorb aircraft should outflow be cutoff
  - ❑ Clustering
    - ◆ Result of competition between:
      - ➪ Efficiency gained by grouping aircraft.
      - ➪ Downstream limitations.
  - ❑ Sector Alignment to Flows

Impact of Convective Activity

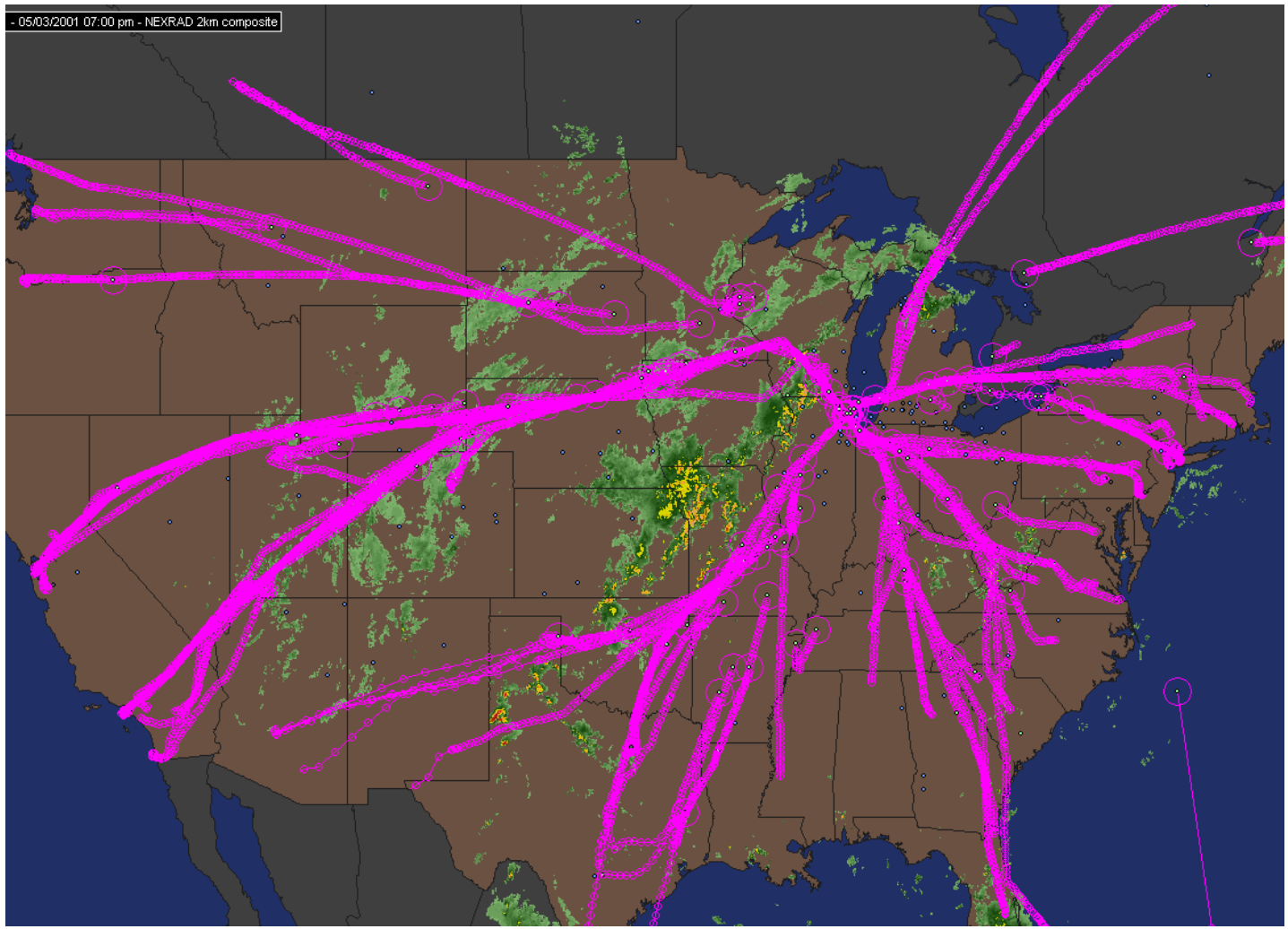
- **Aircraft avoiding convective weather significantly distort flows.**
- **May 11, 2001 7:52 p.m.**

  (All Flights above FL280)



Chicago, May 3, 7:20 pm.

- **Thunderstorms about to impact NW fix.**



Chicago, May 3, 8:59 pm.

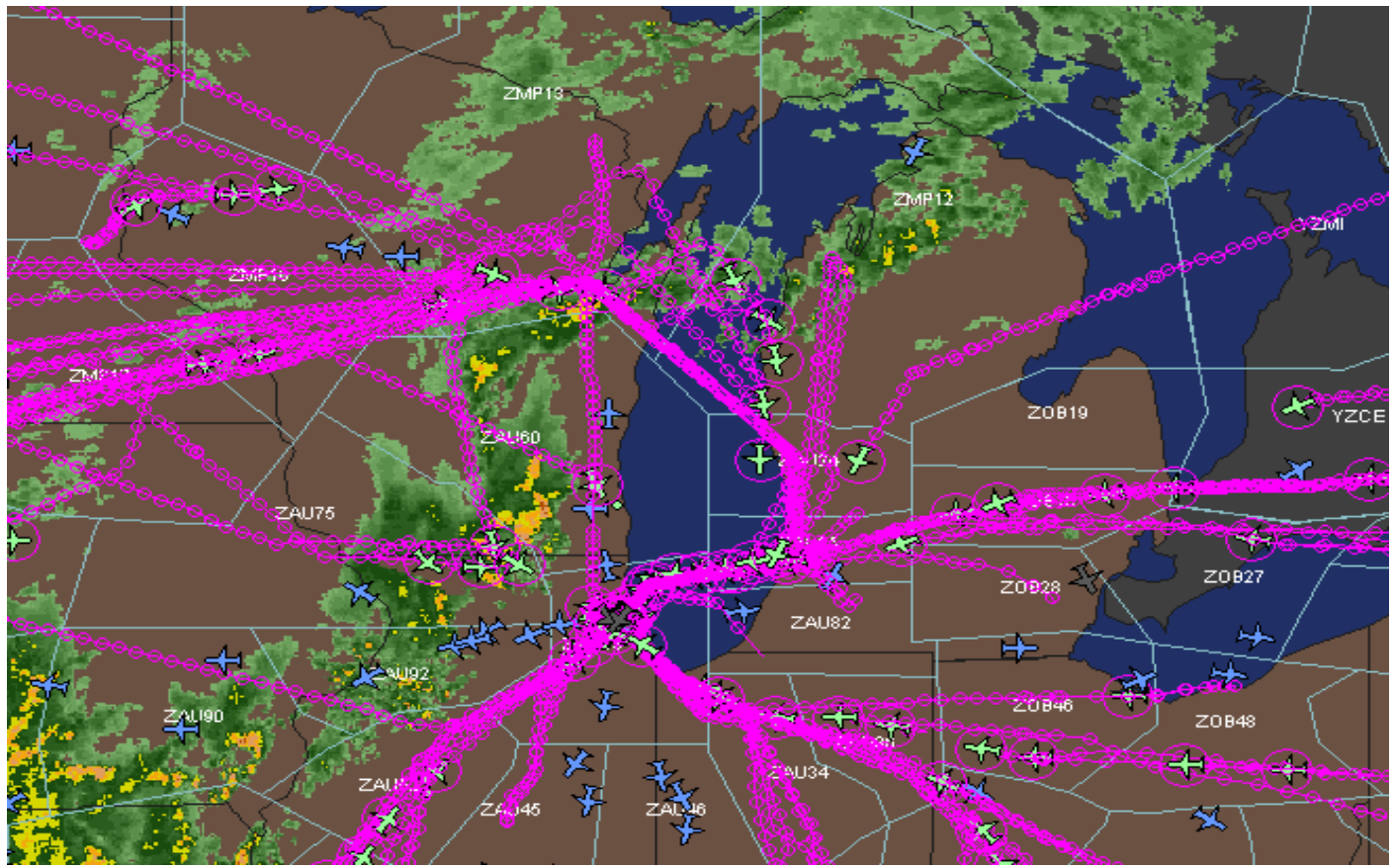
- To deal with complexity associated with increased demand, diverted aircraft are integrated into existing patterns for NE fix.
- Example: Chicago, May 3, 8:59 p.m.

High Sector Boundaries

In-bound ORD

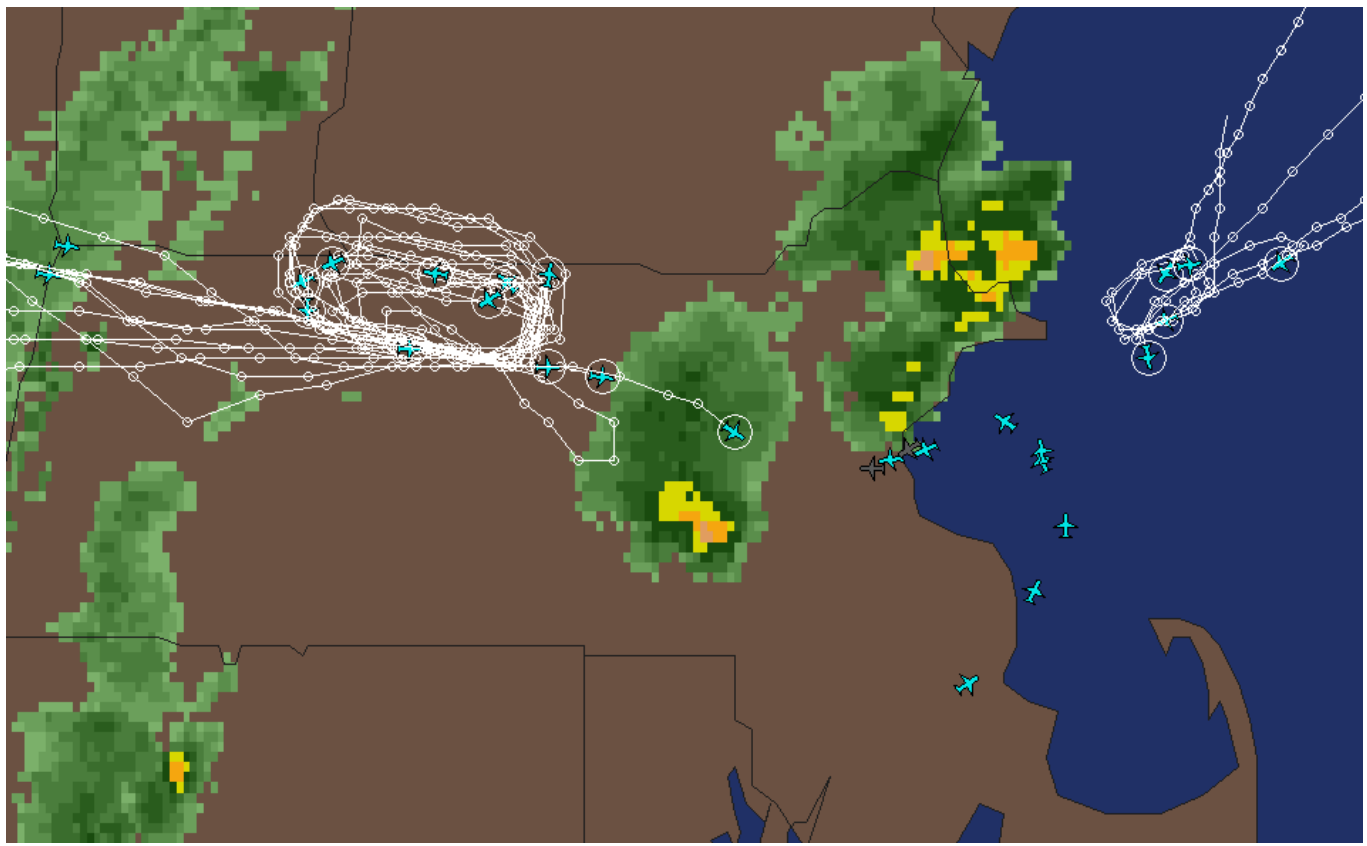
In-bound's Route Flown

Out-bound ORD



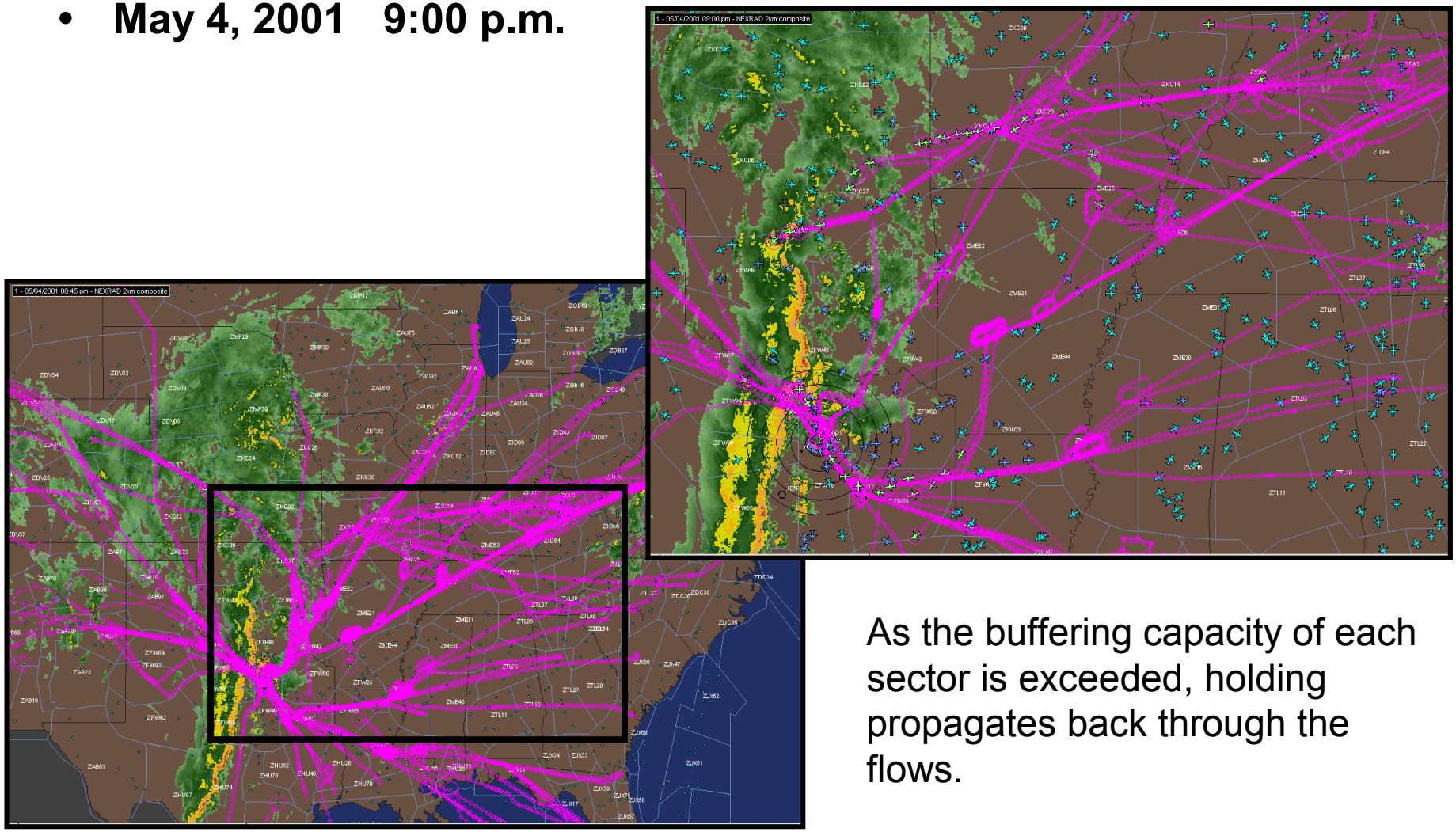
Illustrating the Concept of Buffering: Holding in Boston

- Being forced to hold aircraft causes the buffering capacity to decrease, increasing the complexity for the controllers.
- April 24, 2001 6:33 p.m. 70 Aircraft In-bound



Backward Propagation of Holding: Dallas Fort-Worth

- **May 4, 2001 9:00 p.m.**

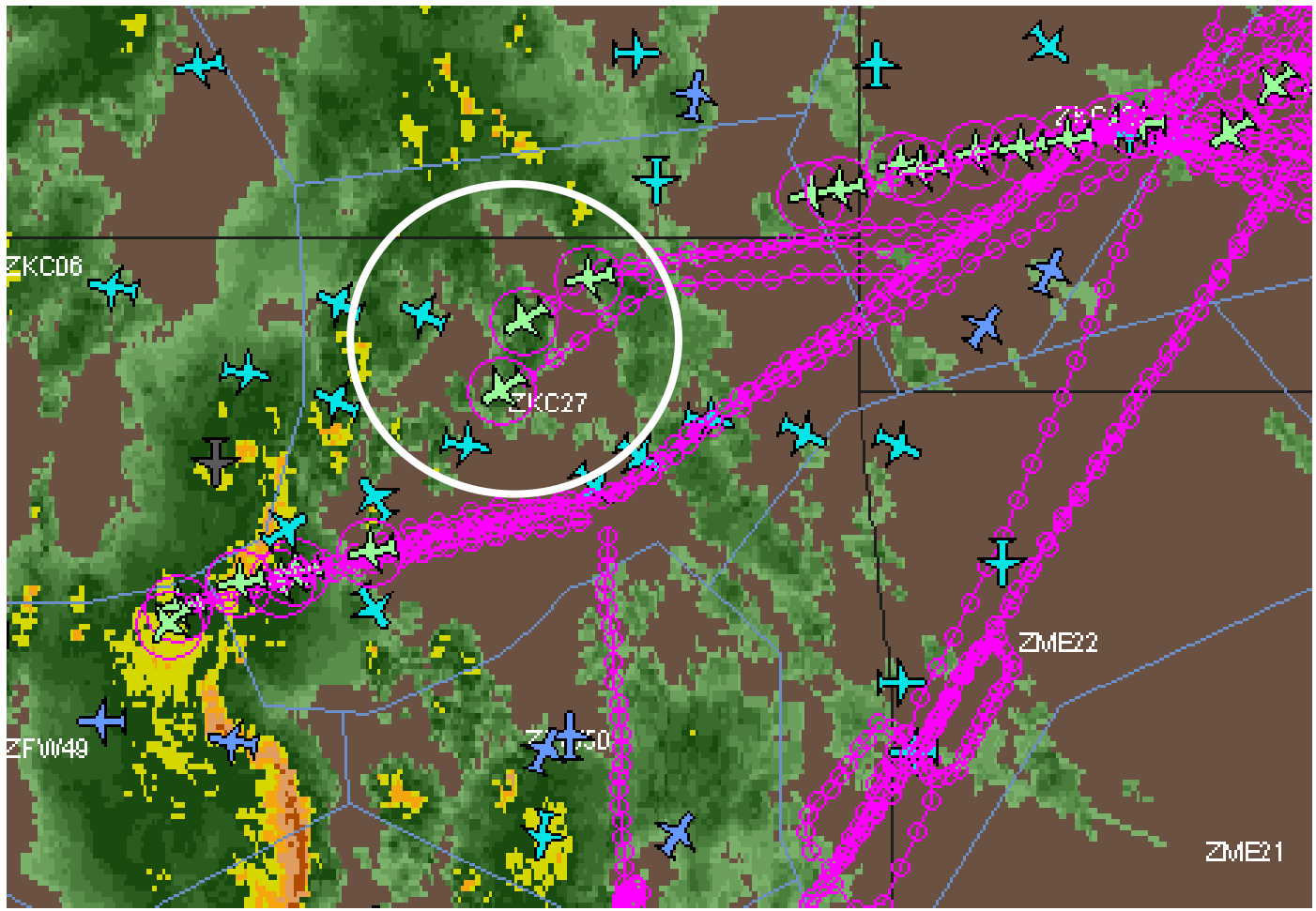


As the buffering capacity of each sector is exceeded, holding propagates back through the flows.

Clustering: Dallas Reroute

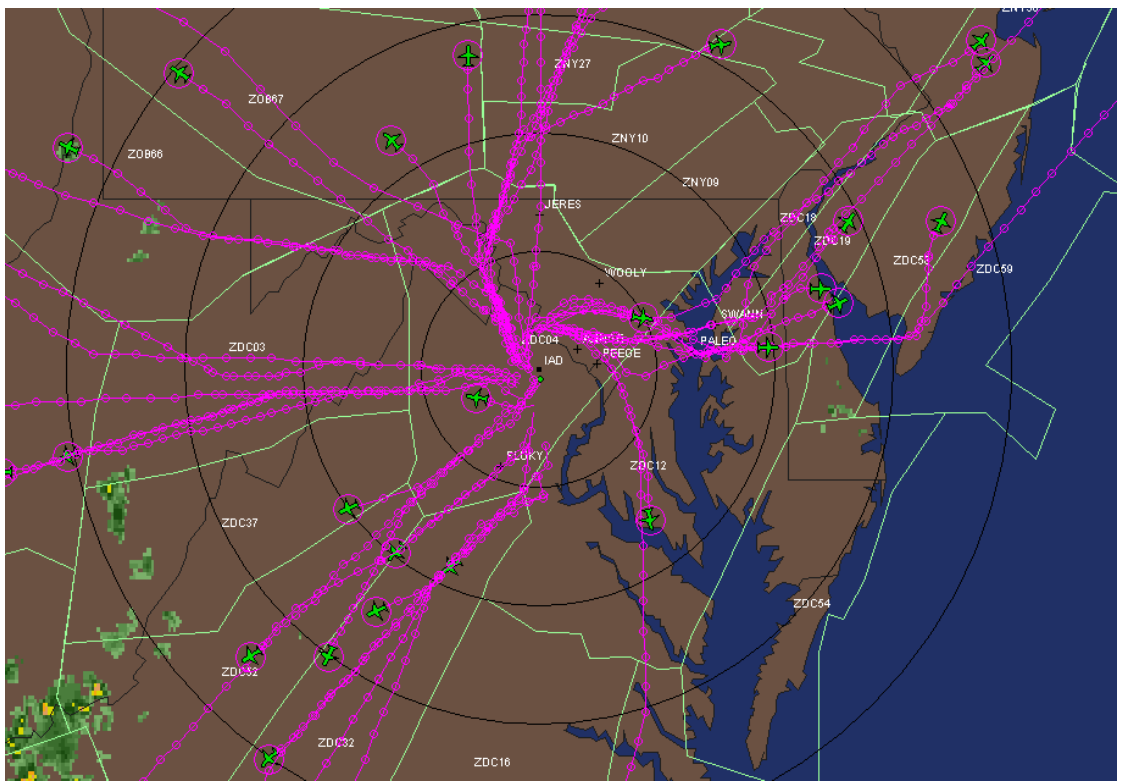
- May 4, 2001 9:05 p.m.

DFW
In-bound



Sectors often Aligned with Major Flows
Departures from Washington - Dulles

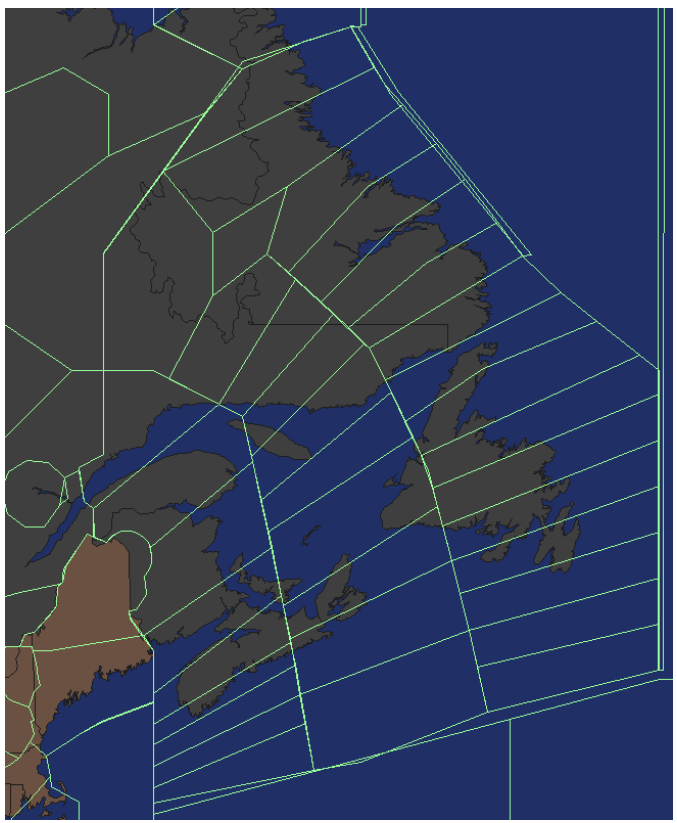
- Sectors are often designed parallel to major flows.
- Reduces ability to buffer as holding will disrupt the major flow.
- May 1, 2001 2:03 p.m. 63 Aircraft Out-bound



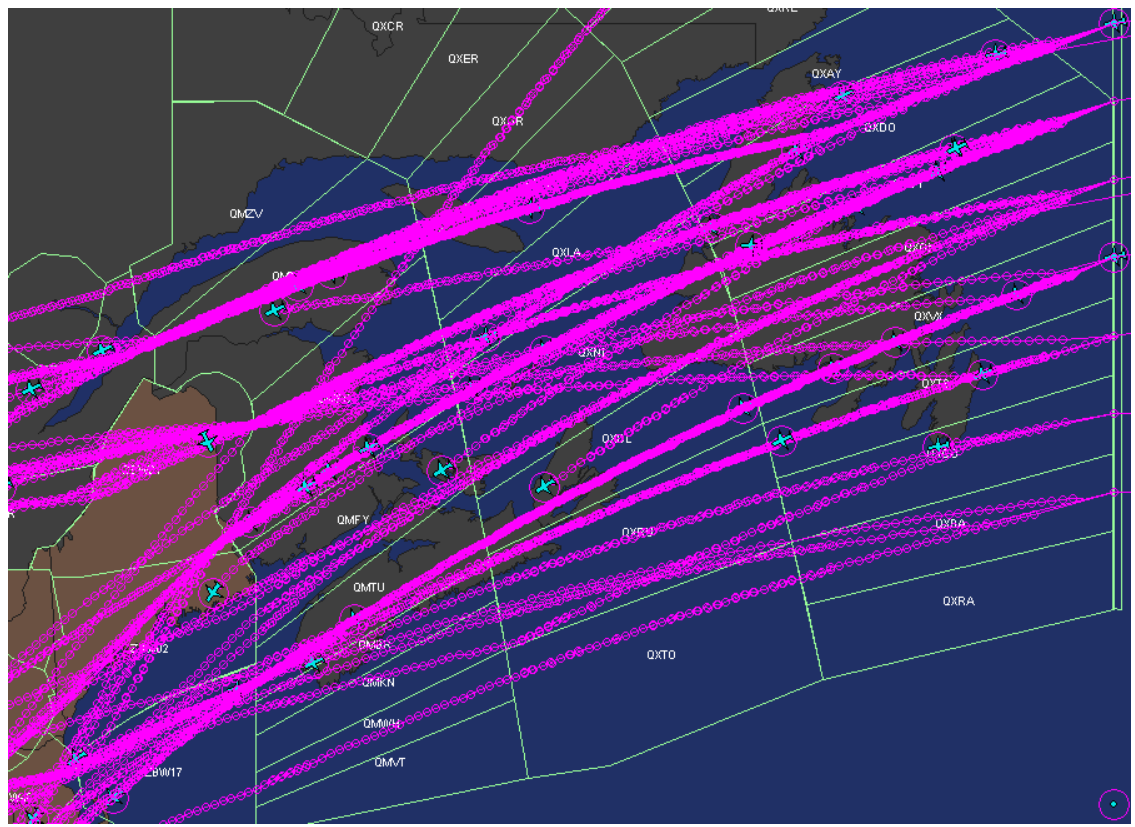
North Atlantic Tracks Transition Area

May 2001 **3:18 p.m.**

Sector Structure

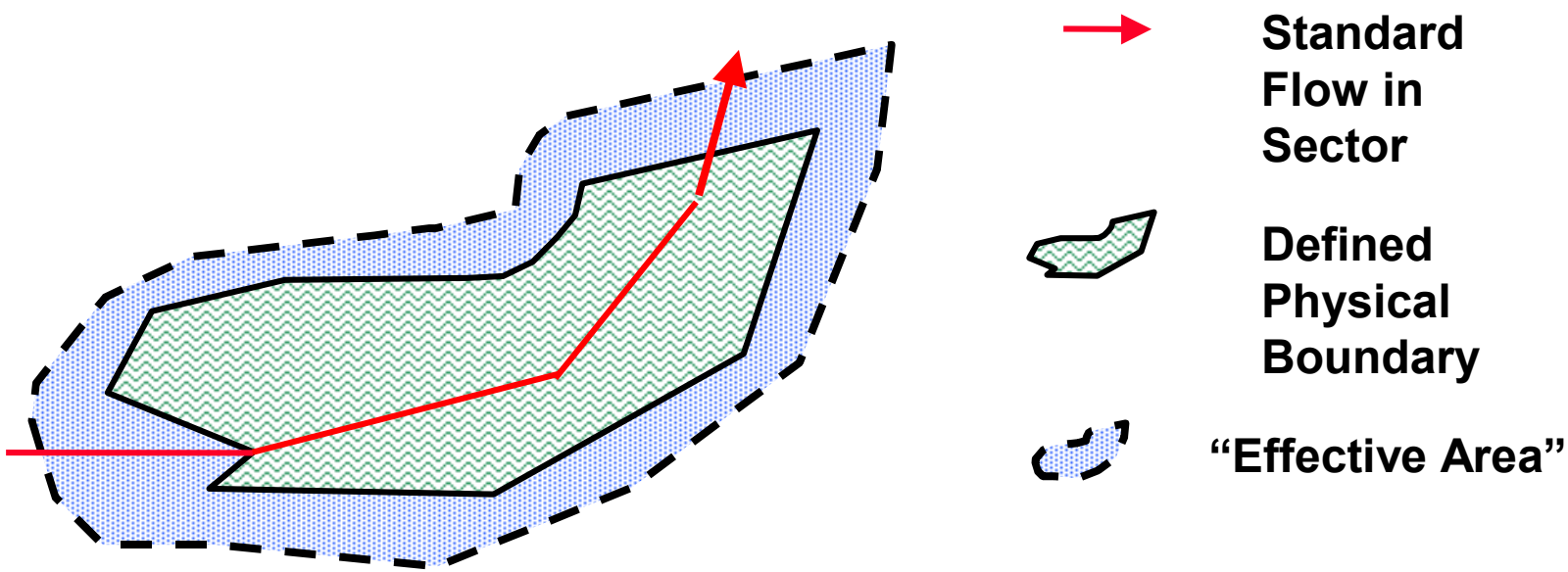


Observed Flows



Observation: The physical definition of a sector is not always appropriate.

- **Identified concept of "Effective Area" of a sector**
  - ❑ Example: Plymouth Position in Boston TRACON:



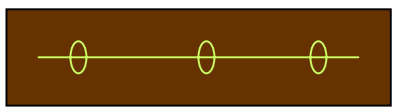
Graphic Courtesy Aaron Karlson, Training Department, Boston TRACON, FAA.

Inter-sector Potential Conflict

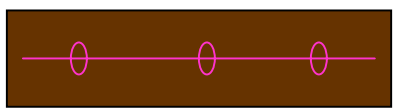
- May 3, 200 1:08 PM
- Difficulty in detecting possible conflict 2 sectors away

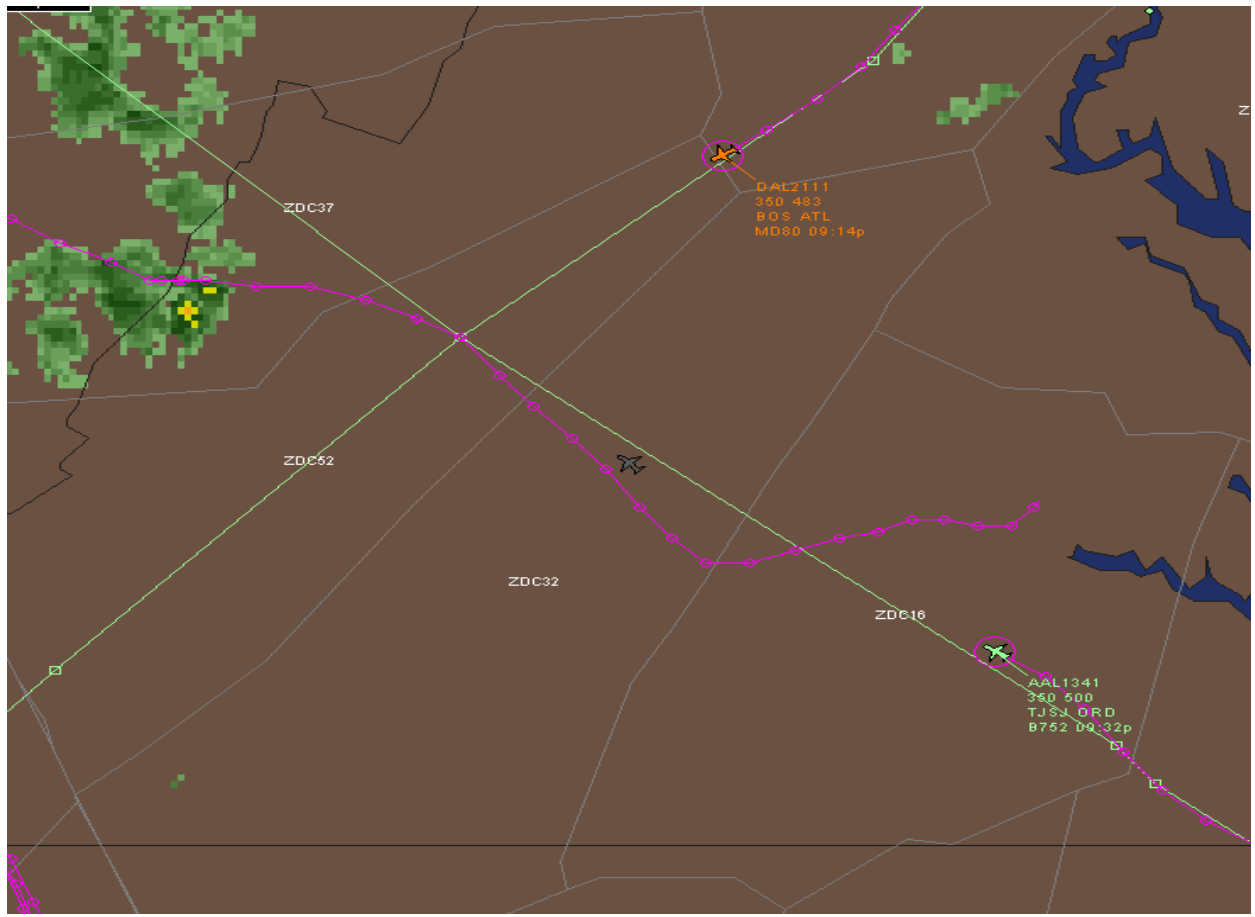
High Sector Boundaries

Flight Plan



Observed Track



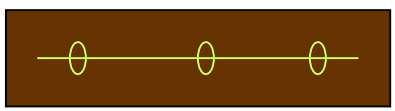


Possible conflict, May 3, 8:11 pm.

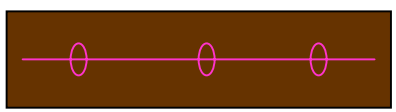
- Difficulty in detecting possible conflict 2 sectors away
- Most aircraft flowing parallel to “major-axis” of the sectors

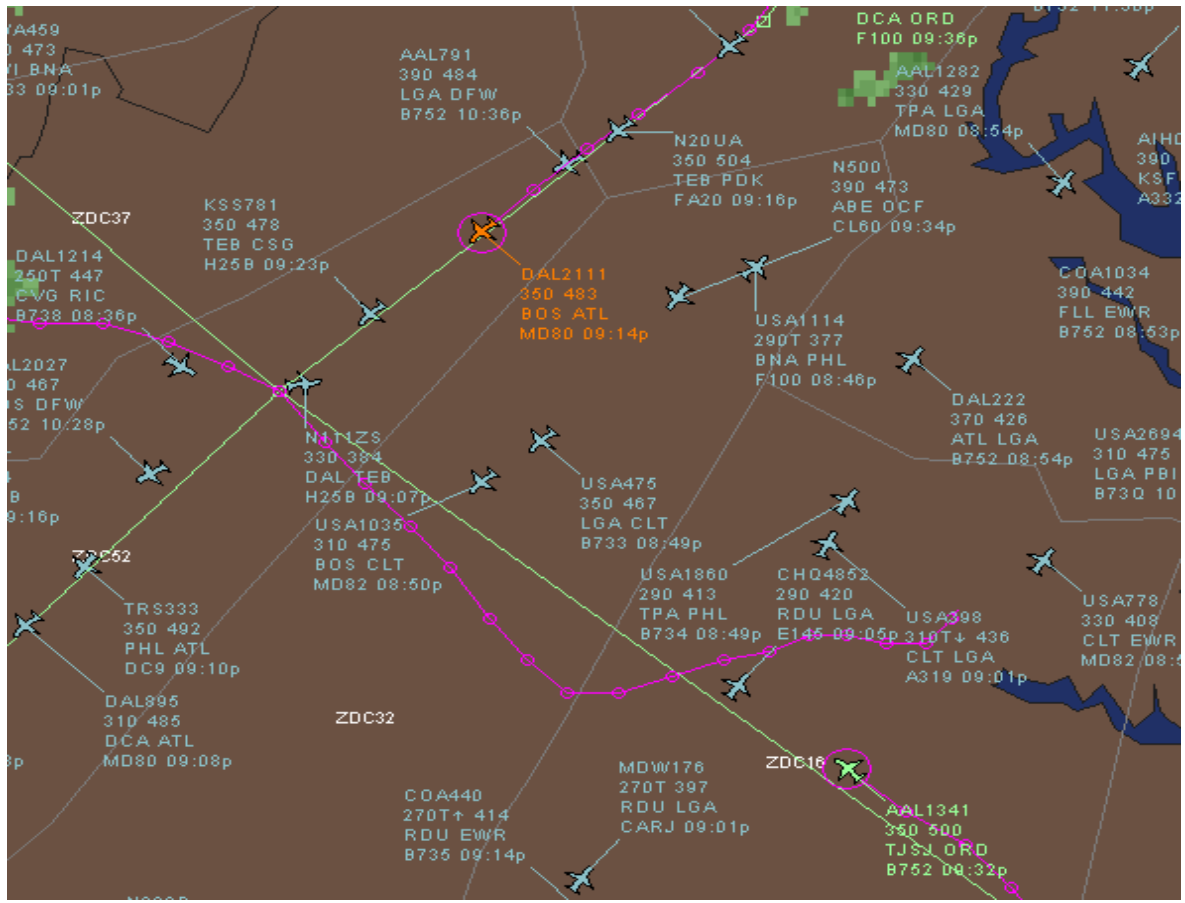
High Sector Boundaries

Flight Plan



Observed Track





Summary

- **Identified Branching Structures in Arrival Patterns**
  - ❏ Aircraft are condensed into flows
  - ❏ Those flows are merged to feed airport arrival fixes
  - ❏ Process reduces complexity of sequencing aircraft, and spreads that task across more controllers.
- **Illustrated Impact on Complexity of**
  - ❏ Special Use Airspace
  - ❏ Temporal Variations in Demand
  - ❏ Weather
  - ❏ Buffering Capacity
- **Significant Observations**
  - ❏ Maximum of 3 flows at a merge point
  - ❏ Only 1 merge point in a sector

Future Work

- **Pursue hypothesis that the observed structure is used to reduce complexity of the system.**
- **Hope to propose a metric based on a formal breakdown of the problem into the effects of:**
  - ❑ Structure
  - ❑ Traffic Load
  - ❑ Operations
- **Tentative formulation:**

$$Complexity = \langle Structure \rangle \otimes \langle Traffic\ Load \rangle \oplus \langle Operations \rangle$$

where ⊗, ⊕ are “to be determined” operators.